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MEMORANDUM

From: Bill Jemison
To: Dr. Daniel Tam, ONR
Date: 6/30/2013

Subject: Progress Report 011–
Chaotic LIDAR for Naval Applications: FY13 Q3 Progress Report (4/1/2013– 6/30/2013).

This document provides a progress report on the project "Chaotic LIDAR for Naval Applications" covering the period of 4/1/2013–6/30/2013.

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FY13 Q3 Progress Report: Chaotic LIDAR for Naval Applications

This document contains a **Progress Summary for FY13 Q3** and a **Short Work Statement for FY13 Q4**.

Progress Summary for FY13 Q3

A high power, wide bandwidth green optical transmitter has been presented for underwater LIDAR work. Previous reports have detailed the generation of 532 nm green light with wideband frequency content, as well as proof-of-concept ranging demonstrations in fiber using an improved 1550 nm infrared chaotic laser signal. We now report the end-to-end integration of the 532 nm source using an improved 1064 nm chaotic signal, demonstrate 150 mW output at 532 nm, and show accurate ranging results in the water.

Detailed Description of Work Performed

Chaotic Fiber Laser Upgrade

In our last report, we detailed a 1550 nm fiber laser with an improved signal for ranging and imaging. We noted that this signal: was noise-like in the time domain; had a uniform, flat power spectral density (PSD) from DC to >1 GHz; and had a sharp thumbtack autocorrelation peak. With this signal, we were able to demonstrate receiver-limited accuracy in ranging in fiber.

We have now developed a 1064 nm fiber laser with the same characteristics (noiselike; flat PSD; sharp autocorrelation). The final architecture and output signals are shown in Figure 1.

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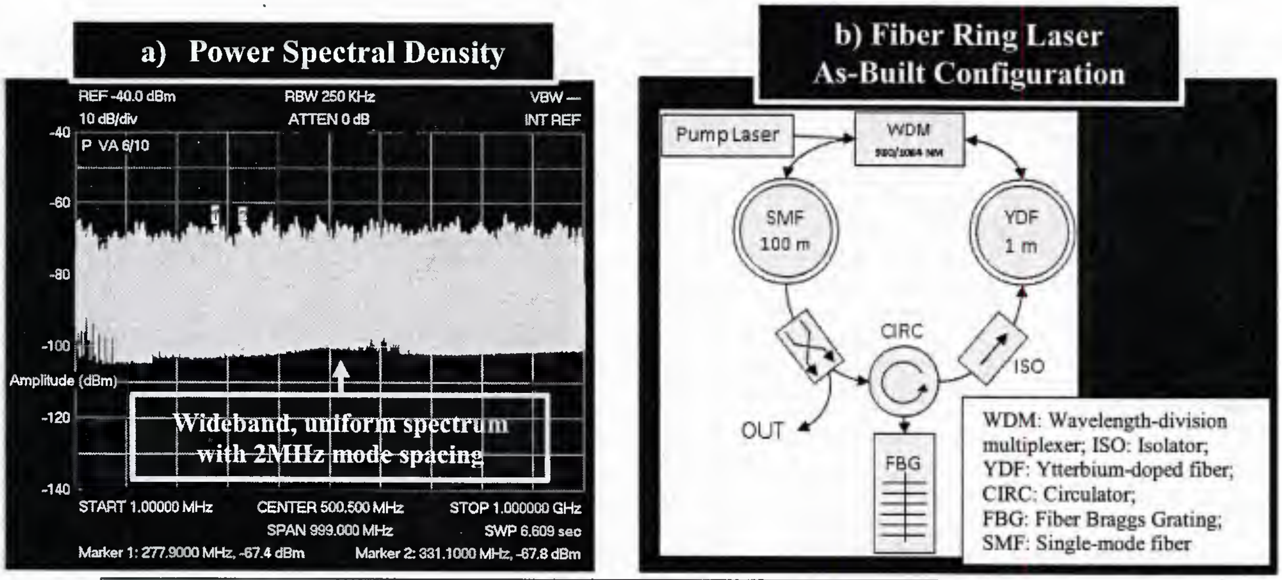

Figure 1. Improved fiber ring laser operating at 1064 nm. The frequency domain is wideband and flat, with closely spaced modes from DC to >1 GHz.

532 nm Source Integration

We have amplified and frequency doubled this improved 1064 nm fiber laser signal to achieve 150 mW of 532 nm green light that carries the noiselike, flat PSD signal. Amplification is performed in two amplifier stages, which boost the 1064 nm fiber laser output from 15 mW to 6.5 W without distortion of the seed signal. Frequency doubling to 532 nm at 3% efficiency is performed using a PPKTP crystal with suitable free space optics.

This integrated 532 nm source outputs a collimated laser beam that is then transmitted into a water tank for proof-of-concept ranging experiments through the water. The performance of the amplifiers and doubler are shown in Figure 2 along with a photograph of the setup.

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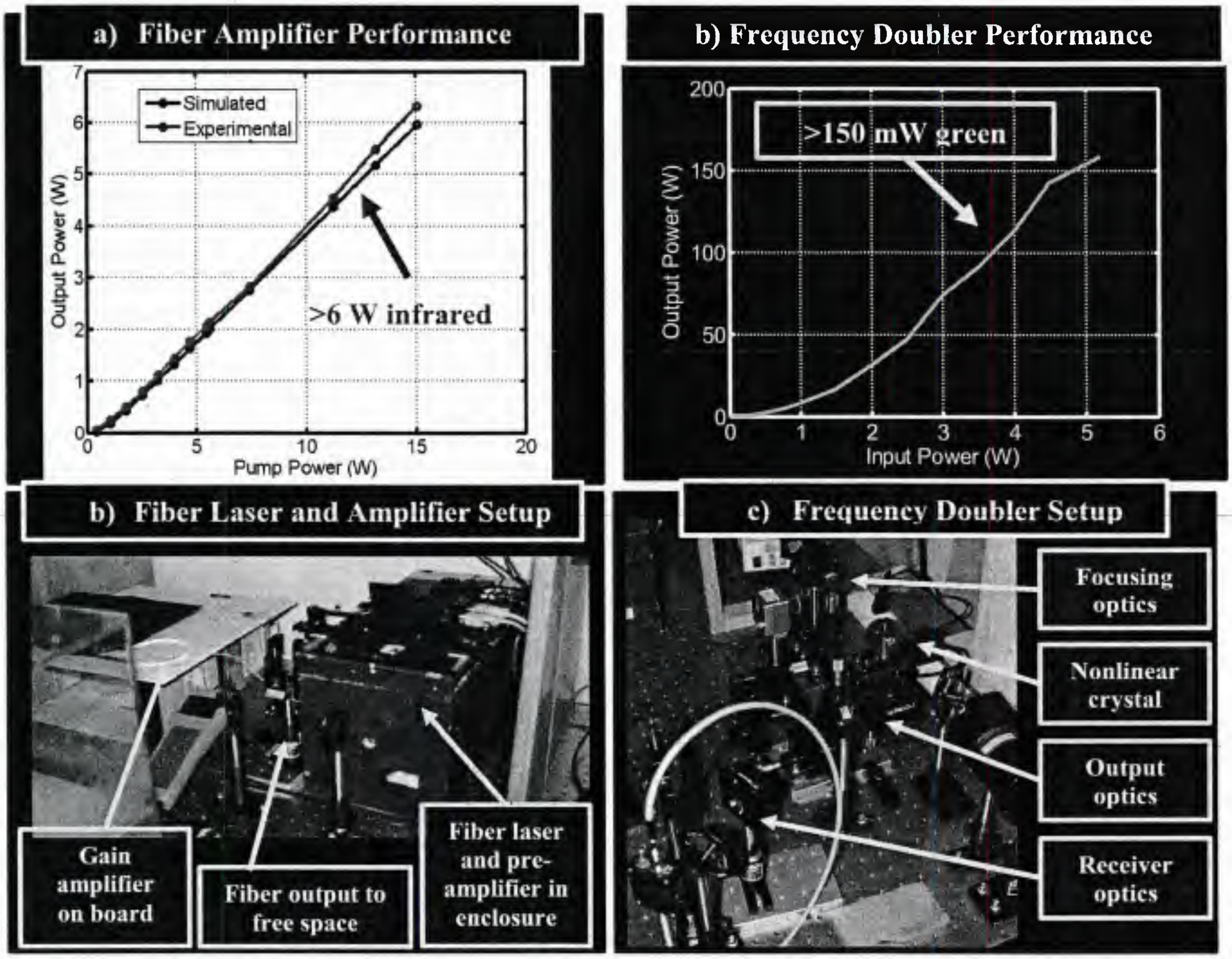

Figure 2. Fiber amplifier stages and optical frequency doubler. The amplifiers boost the wideband fiber laser seed signal from 15 mW to >6 W. The frequency doubler converts the 1064 nm infrared signal to 532 nm green. Output optics collimate the green beam for transmission through the water tank.

Water Tank Ranging Demonstration

The ranging system is shown in Figure 3. The 532 nm beam is split prior to transmission. More than 90% of the power is transmitted through the water and reflected off a mirror "target". The mirror is on a translation stage to vary the target distance, and reflects the beam back to the receiving optics. These optics focus the return beam down onto a photodiode, which detects the intensity modulation of the light and outputs an electrical signal. This analog signal is then digitized by a high-speed oscilloscope and saved as the "return channel" signal. Meanwhile, the other <10% of the power is directed to a second

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photodiode, without being transmitted through the water. This optical signal is also converted to an electrical modulation and is digitized as the "reference channel". The return channel is then a scaled and delayed version of the reference channel: it is scaled by the attenuation of the water and delayed by the path traveled through the water. When the signals are cross-correlated, a peak appears at the time delay corresponding to the round trip distance through the water. The range to the target is then easily inferred.

Preliminary ranging performance through the water tank is shown in Figure 4. As shown, receiver-limited accuracy is achieved in clean water, with +/- 2 cm accuracy corresponding to the 5 GSPS sampling rate of the digitizer used. Meanwhile the peak is sharp, with a FWHM of +/- 5 cm for resolution of closely spaced targets.

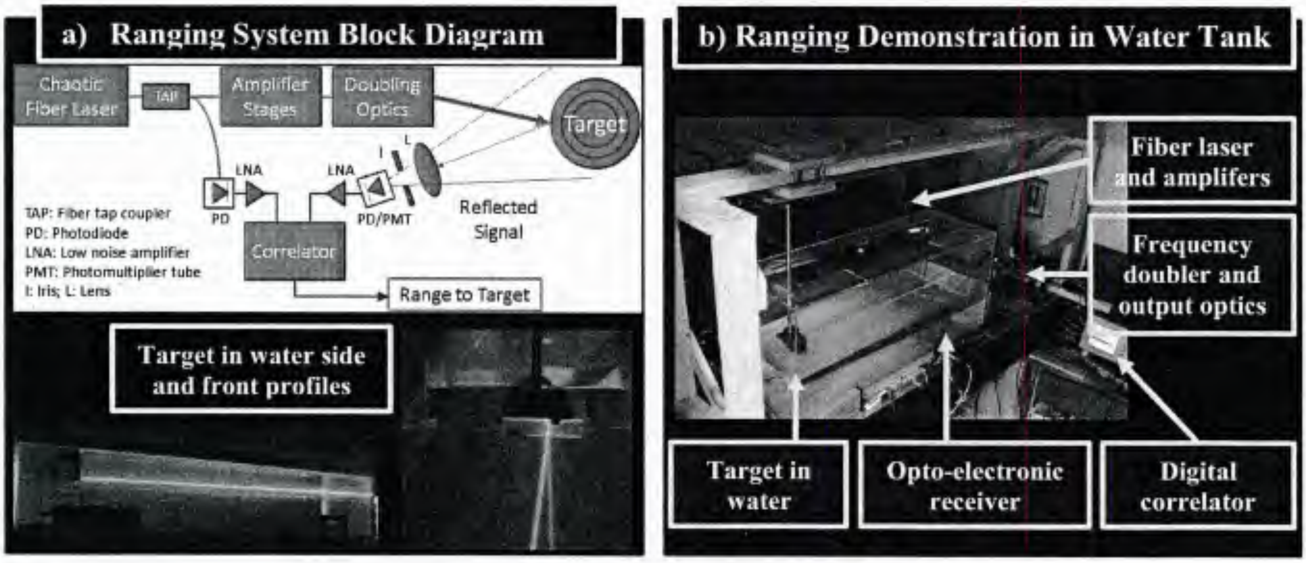

Figure 3. Ranging system using the chaotic green transmitter. A digital correlator computes the delay between the reference signal and the signal returned from the target. The wideband signal allows high resolution ranging with no maximum unambiguous range.

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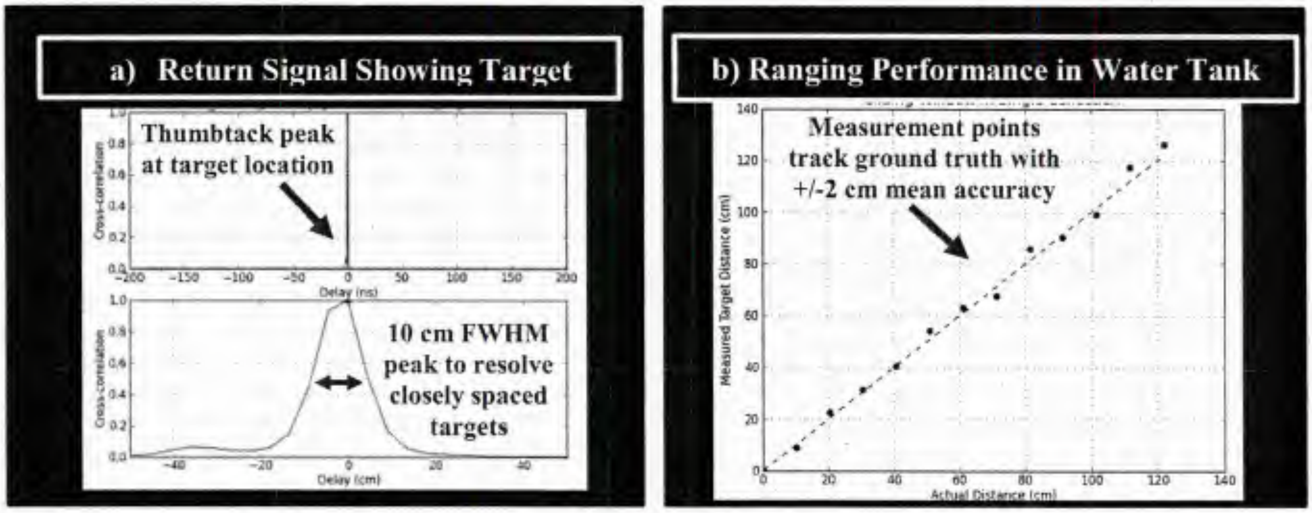

Figure 3. Successful ranging in water tank using chaotic transmitter. The target is clearly seen as a strong "thumbtack" peak in the cross-correlation between the reference and reflected signals. The accuracy is receiver-limited to +/- 2 cm by the sampling speed of the digital correlator. The resolution is 10 cm roundtrip (5 cm downrange) as limited by the bandwidth of the correlator.

Fiber Laser and Amplifier Design Toolbox

In designing and constructing this fiber laser, we have made extensive use of analytical and numerical calculations, and have developed a Matlab toolbox for designing fiber laser and amplifiers, which we have made available to the research community on Matlab's File Exchange. The toolbox calculates output power, lasing threshold powers, laser efficiency, amplifier gain, and amplifier spontaneous emission, and allows the user to vary parameters to optimize their design. Several example graphs are shown in Figure 5. This toolbox allows designers of small fiber laser and amplifier projects to perform informed parameter selection before attempting construction, without having to buy expensive commercial numerical simulation software.

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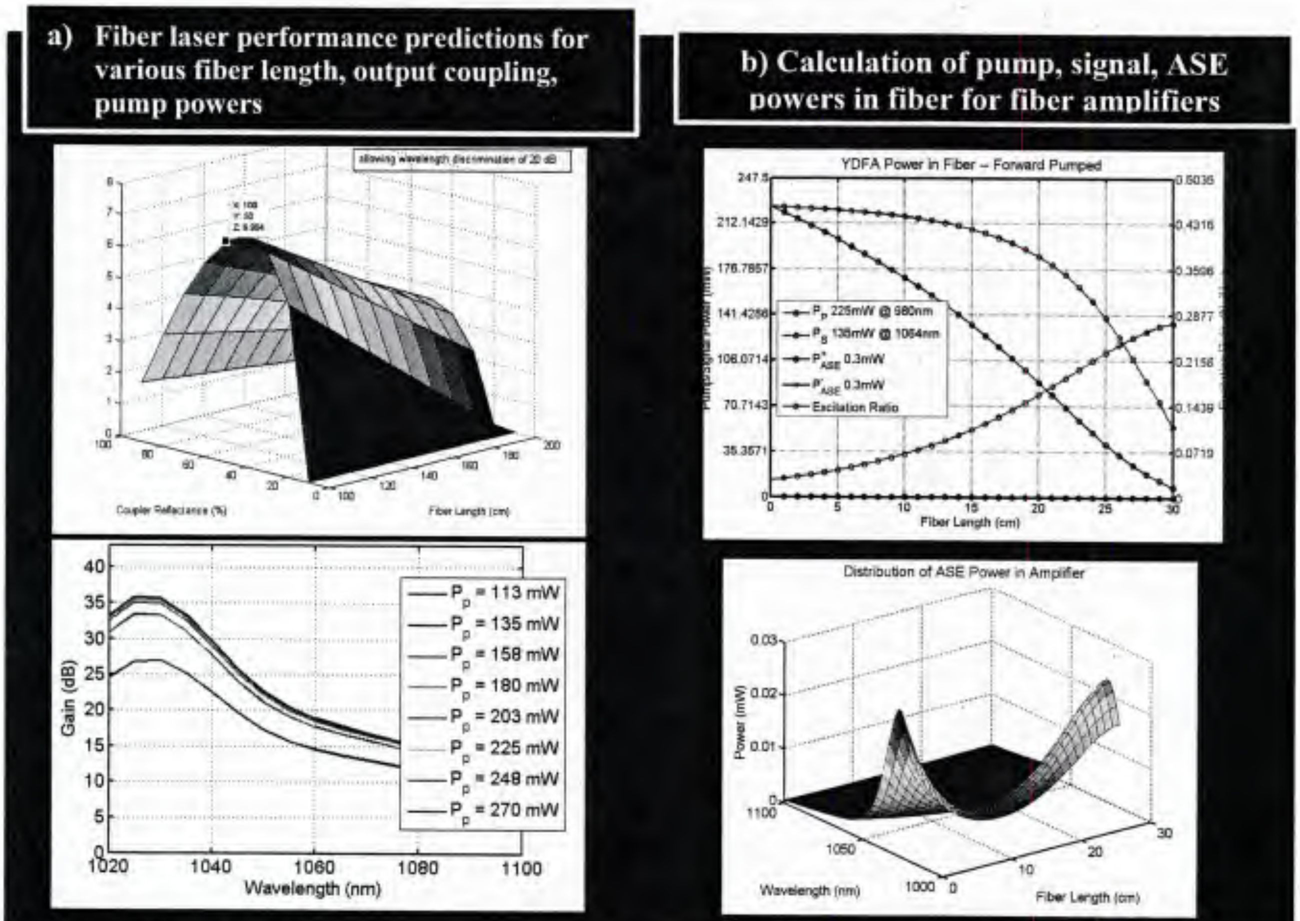

Figure 5. Fiber lasers and amplifiers design toolbox. Analytical and numerical calculations predict performance based on the designer's parameter choices, allowing an optimized design to be selected before construction.

Short Work Statement for FY12 Q4

In the next quarter, the chaotic LIDAR ranging system will be tested for performance in scattering-limited turbid water conditions. Improvements to the analog and digital receiver systems will be made to ensure best performance. Alternative uses, including channel identification, will also be explored.

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